Claims

~~1.~~A new method for determining in-situ bulk tortuosity of the interconnected pores of the reservoir rock, and estimating the bulk permeability of a reservoir formation connected between~~ two wells, by analyzing the seismic signal transmitted into said formation from within one wellbore and received in another wellbore, said seismic signals including selected discrete frequencies. The method comprising~~ seismic transmitters and seismic receivers, such method comprising 1-7 below: (amended)

1.~~Spectrally analyzing said received signals, determining the presence of the Drag-Wave by determining the presence of the frequency side lobes of the Primary seismic wave, of a selected discrete frequency, the frequency side lobes in the said spectrum of the received signals being created by the nonlinear elastic interaction of the Primary mono-frequency seismic wave with the Drag-Wave, the Drag-Wave being generated through solid/liquid coupling as the Primary Compressional Wave propagates through a permeable reservoir formation between two wells, and the said formation has fluid-filled interconnected pores.~~ Transmit a monofrequency signal generated by a seismic transmitter or seismic transmitters and received by a seismic receiver or seismic receivers. (Amended)

~~2.~~2. ~~The method in Claim 1 further comprising:~~

~~Determining the frequency of the side lobes in the frequency spectrum of the received signals, created by summing and differencing of the Primary signal frequency and the Drag-Wave frequency, caused due to elastic nonlinear interaction as the two waves propagate simultaneously through a permeable and elastically nonlinear rock.~~ Analyze the spectral content of the received signal. (Amended)

~~3.~~3. ~~The method in Claim 1 further comprising:~~

~~Using the determined side lobe frequencies, to calculate the Drag-Wave frequency, since the frequency side lobes are the result of the summing and differencing of the Drag-Wave frequency and the Primary input frequency.~~ Identify the side lobes of the monofrequency signal that was transmitted. (Amended)

~~4.~~4. ~~The method in Claim 1 further comprising:~~

The frequency of the side lobes represents (F - Fdrag) and (F + Fdrag), where F is the monofrequency and Fdrag is the frequency of the 'Drag Wave'; these side lobes are generated due to the elastic nonlinear interaction between the monofrequency wave traveling through the rock matrix and the 'Drag Wave' being generated due to the coupling between the matrix and pore fluids.~~Determining the Compressional Wave velocity of the rock formation between the two said wells using the seismic first arrival times of the received and recorded signal transmitted from the seismic source in one well and received in the second well, by knowing the distance between the wells and the time of arrival, the velocity can be calculated.~~ (Amended)

~~5.~~5. Calculate the velocity of the 'Drag Wave' Vdrag by using the Doppler Effect in which $Fdrag/F = Vdrag/(V - Vdrag)$; where Fdrag is the frequency of the 'Drag Wave' (see 4 above), F is the monofrequency, Vdrag is the velocity of the 'Drag Wave' and V is the velocity of the monofrequency signal.~~The method in Claim 1 further comprising:~~

~~Using the value of the Primary wave input frequency and the calculated Drag-Wave frequency along with the calculated Compressional Wave velocity of the rock formation between the two said wells, the Drag-Wave velocity in the said formation between the two said wells can be calculated.~~ (Amended)

~~6.~~6. The bulk tortuosity of the inter-well reservoir rock formation can be estimated by: $Vdrag = Vfluid/\sqrt{T}$, where Vdrag is the velocity of the 'Drag Wave', T is tortuosity, and Vfluid is the compressional velocity of the pore fluids. ~~The method in Claim 1 further comprising:~~

~~Determine the bulk tortuosity of the in-situ reservoir formation between the said two source and receiver wells, based on the calculated Drag-Wave velocity and the compressional velocity of the pore fluids derived from the well logs and the fluid samples from the said wells.~~ (Amended)

~~7.~~7. Once bulk tortuosity has been estimated, bulk permeability can be estimated using Scheidegger's equation $K = \varphi r^2 / 8T$ or other equations generated by Kelder or Peeters.~~The method in Claim 1 further comprising:~~

~~Estimate the bulk permeability of the in-situ reservoir rock formation connected between the two said wells, based on the calculated value of the tortuosity and the values of porosity and average pore radius derived from the well logs and the core samples of the reservoir rock.~~ (Amended)

~~8~~8. The method of claims 1-7 specifically used to determine in-situ bulk tortuosity of the interconnected pores of reservoir rock, and estimating the bulk permeability of a reservoir formation connected between two wells. ~~The method in Claim 1 further comprising:~~

~~Determining the relative amplitude of the Primary input frequency side lobes in relation to the amplitude of the Primary frequency as received and recorded in the said receiver well, using this relative amplitude value as a qualitative measure of the in-situ rock properties of the reservoir formation between one well pair to the next well pair in a field.~~ _(Amended)

9. The method of claims 1-7 specifically used to determine in-situ bulk tortuosity of the interconnected pores of reservoir rock, and estimating the bulk permeability of a reservoir formation in a well between two depth points in that well. ~~A method for determining in-situ bulk tortuosity of the interconnected pores of the reservoir rock, and estimating the bulk permeability of the reservoir formation in a well between two depth points in that well, by analyzing the seismic signal transmitted into the said formation from a source at known depth and receiving and recording that signal at another predetermined and known depth, said seismic signals including selected discrete frequencies.~~ (Amended)

~~The method in Claim 9 comprising:~~

~~Spectrally analyzing said received signals, determining the presence of the Drag-Wave by determining the presence of the frequency side lobes of the Primary seismic signal transmitted, determining the frequency and the velocity of the Drag-Wave, from that calculating the tortuosity of the rock formation and use that value of tortuosity to estimate the rock bulk permeability.~~ (Amended)

Claims 1-7 are the generic claim, while claims 8 and 9 are species of the invention in claims 1-7. If claims 1-7 are not allowable as generic, then applicant elects claim 8 as a species of the generic claim in 1-7. Applicant reserves the right to add claims after this election.

The election above supersedes the provisional election made by Sofia McGuire on 7/23/02.

Applicant is not Double Patenting

This portion of the reply will first briefly describe applicant's invention and then will deal with specific points raised by the examiner. Page references are to Application/Control Number 09/853,190.

Applicant's Invention

This invention describes a method of determining the effects of the dynamic elastic nonlinear interaction between the Fast Compressional Seismic Wave that travels through the rock matrix and a liquid-solid coupled slow compressional seismic wave that travels through the interconnected fluid filled pores. The slow compressional wave has been identified as 'drag wave', since it is generated due to the solid/liquid coupling as the Fast Compressional wave travels through the rock matrix.

When a seismic compressional wave propagates through a permeable rock formation, the bulk of the energy travels through the rock matrix. During the compression and rarefaction cycles the pores with the fluid are squeezed and released, a part of the compressional energy is transferred to the pore fluids. This compressional energy (drag wave) travels through the tortuous path of the interconnected pores. Because of this tortuosity, the 'drag wave' attenuates very rapidly and is seldom detected in the permeable reservoir formations between the wellbores.

However, when a discrete mono-frequency seismic wave propagates through a permeable reservoir formation, it has multiple compression and rarefaction fronts that are precisely spaced in time and travel through the rock matrix at the velocity of that rock formation. The leading wave-front generates a 'drag wave', analogous to a boat traveling in a river. This drag wave interacts with the following compressional front, and in this manner an interaction takes place between the multiple compressional fronts that generate their own 'drag waves' and the following compressional fronts that are traveling through the rock matrix.

Although the 'drag wave' still cannot be detected directly, its signature in the form of elastic nonlinear interaction between the 'drag wave' and the compressional wave, represented by the side-lobes of the primary frequency, can be identified. This signature can only be recognized when a monofrequency seismic compressional wave is used for the analysis. With multiple frequencies, the interaction becomes more complex and the side-lobes smear to the extent that they cannot be detected.

The frequency of the side lobes can be calculated using Fast Fourier Transform as shown in Figure 6. The two side lobes are the consequence of the nonlinear interaction of the primary compressional wave frequency and the 'drag wave' frequency. The side lobe frequencies are the sum and difference of the input frequency and the 'drag wave' frequency. Once the 'drag wave' frequency is established, the 'drag wave' velocity can be calculated as described on Page 4, line 30 and again on Page 12, line 20. This calculation is based on a Doppler Effect that is created where the compressional wave is acting as the source, which is emitting a known mono-frequency and is traveling at a velocity of the compressional wave in the rock matrix. The source couples to the pore fluids and the 'drag wave' is generated; the frequency of the 'drag wave' has been determined using the side lobes of the primary frequency using Fast Fourier transform, and the velocity can be calculated as explained on Page 4 line 30 and on Page 12, line 20.

Once the 'drag wave' velocity is known, and the pore fluid velocity can be obtained from the reservoir data, fluid samples etc, and the bulk tortuosity can be calculated as described on Page 12, line 30 and on Page 5, line 5.

It has been established by different geoscientists through their research that there is a relationship between the tortuosity of the reservoir rocks and their bulk permeability. Scheidegger (1960), Kelder (1998), Peeters (1999) and others have shown that knowing 'drag wave' velocity or the bulk tortuosity of the reservoir rocks can enable one to estimate the bulk permeability, provided that some of the rock parameters are known or can be estimated. Generally these parameters are: compressional and 'drag wave' velocities, fluid viscosity, bulk porosity, bulk density, bulk moduli, grain size, etc. Most of this information is available through core samples, fluid samples, various borehole logs and production information. The part not known prior to this invention was the 'drag wave' velocity, from which tortuosity can be derived.

Evidence (not an Exhaustive List) Indicating Unique Nature of this Patent Application:

No one, to our knowledge, has been able to detect the presence of 'slow wave' or 'drag wave' in reservoir rocks, from one borehole to the other. This Patent Application describes a new method to detect the presence of the 'slow wave' or 'drag wave' in reservoir rocks and this new method has never been published or used in the industry by anyone prior to applicant in conjunction with the invention in the Application.

It is not obvious to anyone that there will be an elastic nonlinear interaction between the 'slow wave' or 'drag wave' and the Primary Compressional wave as it propagates in a permeable reservoir formation or that this interaction will be detected in the form of frequency side lobes of the primary frequency.

It is also not obvious that knowing the side lobe frequencies, one can calculate the 'drag wave' frequency, and using Doppler Effect derive the 'drag wave' velocity (as described in the claims as rewritten).

Once the 'drag wave' velocity is known, there is enough published material based on research by different geoscientists to estimate bulk tortuosity and bulk permeability.

Claims are Patentably Distinct from Claims 1-9 of U.S. Patent No. 6,175,536

First, general comments regarding Khan's U.S. Patent No. 6,175,536 dated Jan. 16, 2001:

U.S. Patent No. 6,175,536 describes a method for determining a degree of acoustic nonlinearity of earth formation using crosswell seismic. The seismic signals include two discrete frequencies transmitted from one wellbore and recorded in another wellbore. The recorded signals are spectrally analyzed; the presence of the sum and difference frequencies and their relative amplitudes is determined. The ratio of sum and difference frequencies along with the harmonics of the primary input frequencies is used as a measure of the nonlinearity of the rock formations between the two wells. The nonlinearity in the earth formations relates to the porosity of the formation, and is a sensitive tool for that measurement. Porosity, especially in carbonates, does not always relate with the permeability of the formation. A different approach is needed to identify in situ permeability of the formations between the wells to map the reservoir flow units with reliability.

U.S. Patent No. 6,175,536 describes using two discrete frequency seismic signals for transmission. The interaction of the two signals is measured to determine the nonlinearity of the interwell formations. Having more than one unique signal propagating simultaneously through the reservoir rock formations blurs some of the other important attributes that could be used for measuring important reservoir rock characteristics. For this reason the method described in the Patent misunderstands the reason for 'widening' or 'spreading' of the received response around the base frequency (column 5, line 45). The 'spreading' is attributed to frequency scatter (column 6, lines 5 to 17), which is incorrect and was not fully understood until the transmission of a monofrequency discrete signal was analyzed. The analysis of the mono-frequency signal clearly shows that there are well defined side lobes, and they relate to a very specific phenomenon of wave propagation in a permeable formation, and do not relate to frequency scatter.

One of the most important reservoir characteristics is the bulk permeability of the reservoir rocks between the wells. Until the invention of the method described in Application/Control Number 09/853,190, there has been no known method of measuring in situ permeability of the reservoir formations between different wellbores.

Now this reply will address specific points raised by the examiner in connection with U.S. Patent No. 6,175,536.

Claims 1-3 of U.S. Patent No. 6,175,536 do not disclose a method for determining the frequency, velocity or amplitude of the Drag Wave because the disclosed method uses two frequencies instead of a monofrequency. Although with a monofrequency signal the 'drag wave' still cannot be detected directly, its signature – in the form of elastic

nonlinear interaction between the 'drag wave' and the compressional wave, represented by the side-lobes of the primary frequency – can be identified. This vital signature can only be recognized when a monofrequency seismic compressional wave is used for the analysis. With multiple frequencies, the interaction becomes more complex and the side-lobes smear to the extent that they cannot be detected. The inability to detect these lobes precisely by the method described using claims 1-3 of U.S. Patent No. 6,175,536 precludes using those claims as a basis to reject any of the claims of Application 09/853,190, as rewritten.

Claims are Patentably Distinct from Claims 1-9 of U.S. Patent No. 6,175,536 in View of Chon *et al*

First, general comments regarding Chon *et al's* U.S. Patent No. 6,009,043 dated Dec 28, 1999:

A method of mapping the continuity of the earth formations between wellbores by analyzing seismic signals transmitted from the source well and recorded in the receiver wells. Compressional and shear components of the seismic signal are separated and their frequency spectrum analyzed at each source and receiver depths. Only the amplitude information in the frequency domain is considered and the phase related information of the crosswell seismic signal is ignored. The Patent describes a method that measures the similarity of the amplitudes of the frequency spectra between source and receiver locations to map the continuity of a formation between source and receiver wells.

The transmissivity function as described in U.S. Patent No. 6,009,043 and U.S. Patent No. 5,144,590 calculates the transmissivity for each source and receiver location by removing the source and receiver effects caused due to borehole coupling and the variations in borehole geometry. It is assumed that the source output and receiver sensitivity will remain the same. The result is a measure of the relative amplitudes of the frequency spectrum of the crosswell seismic signal for each source and receiver location. The method used to calculate the frequency spectrum of each source/receiver seismic signal is to use Fast Fourier transform over a selected time window. The time window is fairly wide to get a better average of the signal characteristics. It is assumed that the measure of the relative amplitudes of the frequency spectra is indicative of the transmission characteristics of the source and receiver locations between the source and receiver wells. Since the solution is under-determined, a certain amount of signal averaging is necessary over a selected depth aperture in both source and receiver wells to get the best estimation.

Due to the laws of reciprocity, where the source and receivers can be interchanged, the amplitudes of the frequency spectral characteristics between each source and receiver location can be compared. Wherever the best correlation between the amplitudes of the source and receiver spectra is found, it is considered that those source and receiver locations are in the same rock formation, which is continuous.

This method of connectivity mapping described in the Patents, using compressional or shear wave signals is mainly designed to map the continuity of the wave guides that are formed when a low velocity rock formation is sandwiched between two high velocity rock formations. The channel waves that are transmitted through wave guides have relatively higher amplitudes compared to other signals that are transmitted where there are no wave guides. This contrast in the amplitudes between the wave guide signal and the signals that are traveling outside the wave guide can be easily detected by the method described in U.S. Patent No. 5,144,590 and U.S. Patent No. 6,009,043. In the subsurface reservoirs, where there is not a great deal of velocity contrast in different rock formations and there are not any well defined wave guides, the results become ambiguous since the method is only analyzing the amplitude characteristics of the frequency spectra averaged over a time window.

In a wave guide, depending on its thickness, there is a characteristic frequency, which resonates and provides the highest amplitude in the frequency spectrum. The amplitude analysis for each narrow band of frequencies in U.S. Patent No. 6,009,043 is useful in determining the wave guide properties, especially the thickness of the low velocity formation that forms the wave guide.

One of the main shortcomings of U.S. Patent Nos. 6,009,043 and 5,144,590 is that they both are limited to the analysis of the amplitudes of the frequency spectra of the crosswell seismic signals, over certain time windows. The high amplitudes that can be easily differentiated in the crosswell seismic signals are mostly related to channel waves in the wave guides. Using the Patented method, if the wave guides are not prominent in the reservoir formations, the continuity of those formations cannot be mapped. In a lot of siliciclastic reservoirs, there is not a great deal of velocity contrast between the fluvial shales and sandstones, in those conditions the continuity map generated using these Patents is not reliable. In carbonates where there is no direct relationship between the velocity of the rock and its porosity the results can be even more ambiguous. Additionally, the method described in the Patents cannot map the continuity of the high velocity formations that are connected between two wellbores. The connectivity map example shown as Figure 2 in U.S. Patent No. 6,009,043 is from a carbonate reservoir and the results are not clear and are ambiguous, since they do not correlate with the sonic log shown in Figure 2.

U.S. Patent Nos. 6,009,043 and 5,144,590 do not describe any method that can be used to detect the 'slow wave' or 'drag wave'. The 'slow waves' or 'drag waves' are attenuated rapidly since they are highly diffusive and for this reason cannot be detected directly in situ reservoir formations.

Now this reply will address specific points raised by the examiner in connection with Claim 5 being rejected as unpatentable over claims 1-9 of U.S. Patent No. 6,175,536 in view of Chon, *et al.*

Claim 5, as previously written, dealt with the calculation of 'drag wave' velocity. This calculation depends on the detection of the side lobes described above, which requires the use of a monofrequency, as described above.

Claims 1-9 of U.S. Patent No. 6,175,536 do not disclose a method for determining the frequency, velocity or amplitude of the Drag Wave because the disclosed method uses two frequencies instead of a monofrequency. Although with a monofrequency signal the 'drag wave' still can not be detected directly, its signature in the form of elastic nonlinear interaction between the 'drag wave' and the compressional wave, represented by the side-lobes of the primary frequency, can be identified. This vital signature can <u>only</u> be recognized when a monofrequency seismic compressional wave is used for the analysis. With multiple frequencies, the interaction becomes more complex and the side-lobes smear to the extent that they cannot be detected. Chon *et al* also does not describe any method that can be used to detect the 'slow wave' or 'drag wave'. The 'slow waves' or 'drag waves' are attenuated rapidly since they are highly diffusive and for this reason cannot be detected directly in in-situ reservoir formations. The inability to detect these waves or to detect the side lobes that allow for calculations regarding these waves precisely by the method described in claims 1-9 of U.S. Patent No. 6,175,536 or in Chon *et al* precludes using those claims in view of Chon *et al* as a basis to reject any of the claims of Application 09/853,190, as rewritten.

Please note that col. 6, lines 19-31 of Chon *et al* do not disclose a calculation for Drag-Wave velocity but rather disclose the transmissivity function, described above. This function does not allow calculation of Drag-Wave velocity.

In light of the above, it would not be obvious to anyone to use U.S. Patent No. 6,175,536 in view of Chon *et al* to calculate Drag-Wave velocity since neither patent allows measurement or calculations regarding drag waves.

Claims are Patentably Distinct from Claims 1-9 of U.S. Patent No. 6,175,536 in View of Stearns

First, general comments regarding Stearns' U.S. Patent No. 5,074,149 dated Dec. 24, 1991

U.S. Patent No. 5,074,149 describes a method of measuring the concentration of the fine granular material (toner) in an electro-photographic machine. The porous material consists of the carrier granules in the range of 100 to 150 micro-meters, and the finer toner material in the order of 10 micro-meters in diameter. As the toner material is depleted by the usage, the transmission characteristics of an acoustic wave signal through the sample change. The measurement of the degree of this change is used to determine the toner concentration.

The porous material is saturated with dry gaseous fluid (air), which simplifies the transmission mode of the acoustic wave through the sample, since only the slow-compressional wave is present. The other two modes, of Primary compressional wave

and shear waves are not generated. This mode of wave propagation is very much simplified and different than the real world in a reservoir rock formation where the wave motion is coupled between the rock matrix and its pore fluids.

Biot's theory (1956) predicted that when a seismic wave propagates through a saturated porous medium, three types of waves are generated. Two are compressional waves and one shear wave. The two compressional waves can be identified as, the fast or primary compressional wave and a slow compressional wave. The slow compressional wave is the consequence of the coupling between the rock matrix and its pore fluids. In most reservoirs pore fluids invariably have liquid component in the form of water, oil or liquid gas due to high reservoir pressure. There are no real world examples where sedimentary rocks have totally dry air or gas. The measurement of the 'slow' wave is very difficult in liquid filled porous media, since the relative amplitudes of the Primary compressional wave and the Shear wave are much larger than the 'slow' wave. The method described in U.S. Patent No. 5,074,149 would not be applicable in measuring 'slow' wave in situ reservoir rocks.

Biot's theory also predicts that the slow wave cannot be observed at some distance from its origin due to its diffusive nature and high attenuation. Slow wave remained a theoretical curiosity until 1980, when Plona (1980) was able to observe it in the laboratory using sintered glass beads. Mayes et al, (1986) observed it in synthetic porous materials other than glass beads. <u>To our knowledge no one else has been able to record or measure 'slow' wave in situ sedimentary rocks.</u>

Johnson and Plona (1982) demonstrated the relationship of the 'slow' wave velocity with the tortuosity of the pores. Scheidegger (1960) had shown that there was a relationship between the tortuosity of the pores in a rock with its in situ permeability. Based on theoretical studies and practical work in the laboratories, it has been established that if the velocity of the 'slow' wave can be measured, tortuosity and permeability of the sedimentary in situ rocks can be approximated and estimated. To get the information needed to estimate the permeability based on tortuosity, one has to know the average grain size of the rock, its porosity, pore fluid viscosity, temperature, compressional velocity of the rock matrix and the pore fluids, bulk density, bulk modulus etc; most of this information can be acquired from the borehole data and the core samples. <u>The key factor for estimating the in situ sedimentary rock tortuosity and permeability is to detect the presence of the 'slow' wave and measure its velocity.</u>

Stearns' U.S. Patent No. 5,074,149 is an intelligent application for electro-photographic printing based on the research knowledge acquired by different geoscientists as a result of their quest for proving the existence of the 'slow' wave, and to be able to measure its velocity in laboratory samples using dry gas or air, which does not couple to the solid material, thus simplifying the measurement. This Patent does not provide any new information or describe a new method of detecting or measuring 'slow' wave in a sedimentary rock that has liquid saturation. <u>In fact the Patent write up acknowledges the difficulty of such a measurement in column 2, lines 35 to 50</u>.

Now this reply will address specific points raised by the examiner in connection with Claim 6 being rejected as unpatentable over claims 1-9 of U.S. Patent No. 6,175,536 in view of Stearns *et al.*

Claim 6, as previously written, dealt with determining bulk tortuosity of in-situ reservoir formation based on the calculated Drag-Wave velocity and the compressional velocity. As has been indicated above, there has been theoretical understanding of how to use Drag-Wave frequency and velocity information to determine bulk tortuosity, but until the invention of the method in Application 09/853,190 no one has been able to put theory into practice and actually make measurements that allow calculation of the velocity and frequency of the Drag-Wave. The benefits of knowing bulk tortuosity of a reservoir – and thereby having the ability to estimate permeability – are so great that many have tried and failed. This fact alone indicates that claim 6 cannot be rejected on the grounds of obviousness because none of those people having ordinary skill in the art developed the method in claim 6 (now rewritten as new claim 6). Also, the rejection of claim 6 was based on claims 1-9 of U.S. Patent No. 6,175,536, which cannot be used as the basis of rejection either because of reasons already cited above.

Stearns does not disclose a method for determining bulk tortuosity in reservoir formations. Stearns' method is not effective in pore spaces that are filled with liquid and in large areas where the drag wave diffuses too quickly for measurement by his method. Thus, Stearns cannot be used, individually or in combination, as the basis of rejection of claim 6.

Claims are Patentably Distinct from Claims 1-9 of U.S. Patent No. 6,175,536 in View of Liu *et al*

First, general comments regarding Liu *et al* U.S. Patent No. 4,964,101

This Patent describes a method of measuring the fluid mobility in an earth formation that is in close vicinity of a wellbore, by using the tube wave propagation in the liquid column of the well. The method described makes an effort to map the permeability of a formation by measuring the changes in the velocity of the tube wave that travels up and down the wellbore. Since the effects of the mudcake that is formed during drilling around the borehole surface changes the physical characteristics of the borehole wall, a mud-cake compensated model has been described. The accuracy of this model depends on the assumptions that are made and the quality of the measured parameters.

The method described is limited to the vicinity of the wellbore, and does not take into account the changes in the wellbore diameter due to drilling and mud circulation effects (washouts, etc.).

Since Biot's prediction of the existence of the 'slow' wave (1956), many geoscientists have developed relationships between the velocity, tortuosity and the permeability of the sedimentary reservoir rocks. Johnson and Plona (1982) related the tortuosity of the pores to the 'slow' wave velocity and the pore fluid velocity. Scheidegger (1960) showed the

relationship of the permeability with tortuosity. Kelder (1998) and Peeters (1999) have shown 'slow' velocity may be directly related to steady state permeability. Others in different universities and research centers have done similar work. Until Application/Control Number 09/853,190, the critical element still remained – how to detect the presence of the 'slow' wave and its velocity across two wellbores that may be a few hundred or few thousand feet apart. U.S. Patent No. 4,964,101 does not describe any new method of either detecting the presence of the 'slow' wave or measuring its velocity in sedimentary rocks over a distance of few hundred or few thousand feet, or across two wellbores that may be a few hundred or few thousand feet apart. It simply discloses theory regarding permeability in an appendix. The fact that this theory of the relationship between bulk tortuosity and bulk permeability has not resulted in practical use in oilfield reservoirs for 42 years strongly indicates that the invention in Application 09/853,190 is not obvious to those of ordinary skill in the art.

Now this reply will address specific points raised by the examiner in connection with Claim 7 being rejected as unpatentable over claims 1-9 of U.S. Patent No. 6,175,536 in view of Liu *et al.*

The theory stated in Liu *et al*, as stated above, was not accompanied by a practical method that would facilitate its use. Thus, Liu *et al* cannot be used as a basis for stating that claim 7 (both as submitted and as currently written) was obvious because the practical use of the theory was only made possible by the invention in Application 09/853,190 that allowed measurements that allowed calculation of the velocity of the Drag-Wave. Thus, claim 7 is patentable over claims 1-9 of U.S. Patent No. 6,175,536 in view of Liu *et al.*

Applicant was not Anticipated and the Invention is not Obvious

The examiner relies on essentially the same arguments used to reject claims 1-8 on the basis of non-statutory double patenting/obviousness as he did for anticipation and obviousness. Applicant would re-urge the same counter arguments as used above to counter the anticipation arguments and obviousness arguments.

Applicant would also urge the following. Applicant was not anticipated by any of the above patents or claims. As has already been shown, the other patents do not disclose methods that allow precise measurements of the side lobes of a monofrequency signal. This measurement is crucial in calculating the Drag-Wave velocity, which in turn is used to determine bulk tortuosity and then bulk permeability of the reservoir.

No one, to our knowledge, has been able to detect the presence of 'slow wave' or 'drag wave' in reservoir rocks, from one borehole to the other. Our Patent Application describes a new method to detect the presence of the 'slow wave' or 'drag wave' in reservoir rocks and this new method has never been published or used in the industry by anyone prior to applicant in conjunction with the invention in the Application.

It is not obvious to anyone that there will be an elastic nonlinear interaction between the 'slow wave' or 'drag wave' and the Primary Compressional wave as it propagates in a permeable reservoir formation or that this interaction will be detected in the form of frequency side lobes of the primary frequency.

It is also not obvious that knowing the side lobe frequencies, one can calculate the 'drag wave' frequency, and using Doppler Effect derive the 'drag wave' velocity (as described in the claims as rewritten).

Thus, no one has been able to estimate permeability in reservoirs until now.

Request

Applicant requests that claims 1-9 be allowed as rewritten.